C-CORE Publication No. 89-1

CANADIAN CONFERENCE ON ELECTRICAL AND COMPUTER ENGINEERING
CONGRES CANADIEN EN GENIE ELECTRIQUE ET INFORMATIQUE
Vancouver, B.C., Canada, November 3-4 novembre 1988

TIME-DOMAIN MODELLING OF OCEAN CLUTTER FOR GROUND WAVE RADAR

R.H. Khan, B.J. Dawe and J. Walsh
Centre for Cold Ocean Resources Engineering
Memorial University of Newfoundland
St. John's, Newfoundland, A1B 3X5, CANADA

ABSTRACT

The detection performance of high frequency ground wave (HFGW) radar systems, for over-the-horizon detection of surface ships, is limited by the back scattering returns from the ocean surface. An improved modelling of the ocean clutter is the key to enhanced target detection with HFGW radar; this would enable clutter suppression techniques to be refined and a higher signal-to-noise ratio to be achieved.

Time-domain analysis of HFGW radar clutter signals has shown that the back scattering from ocean waves possess a limited temporal coherence period. This period is typically short compared to the radar observation period. We propose a wave packet model for the dominant components of the ocean back scattering signal and suggest a technique to exploit this non-stationary characteristic of the ocean clutter to improve target detection performance. The technique is based on the Wigner-Ville distribution, which is an emerging tool for non-stationary spectral analysis. Results are presented to demonstrate the enhanced detection performance of the proposed technique.

INTRODUCTION

The line-of-sight propagation characteristic of operational radars severely restricts the detection range for targets at or near the ocean surface. High frequency (HF) radar however, operating in the ground wave (GW) mode, is able to eliminate this "over-the-horizon blindspot" of the microwave sensors.

The HF radar frequency is from 3 to 30 MHz; at these frequencies electromagnetic waves are capable of over-the-horizon (OTH) propagation in either the sky wave or GW mode. We are primarily concerned with the GW mode of propagation in which most of the radar energy is guided along the air/sea-water interface. Any target which introduces a discontinuity in the path of the radar waves will cause a portion of the energy to be reflected. Such targets include icebergs, ships and low-flying aircraft. Radar energy back-scattered from the ocean surface is the dominant interference mechanism so detection is difficult if the target Doppler frequency falls in the vicinity of any characteristic peaks of the ocean Doppler spectrum.

We propose that the maximum range of target detection can be considerably increased by establishing characteristic time-domain differences between the target and ocean clutter signals. In our wave packet model for the dominant components of the ocean clutter signal, ocean clutter is modelled as a non-stationary process. We propose a technique, based on the Wigner-Ville distribution, to increase the target signal power relative to the clutter signal power. The technique was applied to process data from a ship detection experiment and enhanced detection performance was reported.

THE WAVE PACKET MODEL

Fig. 1 shows the spectrum of a typical HFGW radar signal, with an operating frequency of 25.4 MHz. The spectral peak at 0.225 Hz corresponds to a ship moving radially away from the radar at a speed of 2.6 knots. The dominant feature of the ocean clutter is the first order "Bragg" scattering [1] at ± 0.51 Hz; the second order scattering spectra [2,3] are also clearly visible. The relative amplitudes of the target signal and the ocean clutter suggest that clutter suppression techniques must be investigated if reliable target detection is to be achieved.

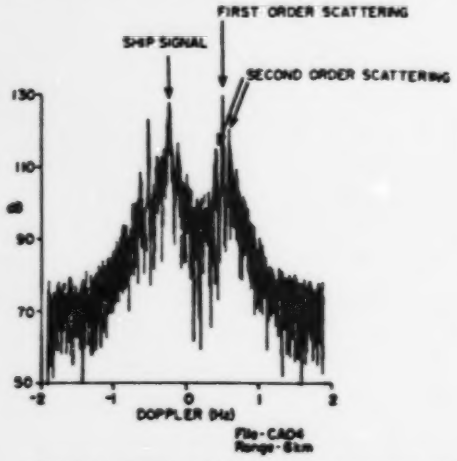

Fig. 1. Typical HFGW radar power spectrum showing scattering returns from the ocean and the signal from a ship.

Time-domain fluctuation of the ocean clutter signal is consistently observed in field experiments with HFGW radar. However, we are not aware of any attempts to investigate the magnitudes and frequency content of these fluctuations. A simple model is proposed to account for the dominant characteristics of these fluctuations. We wish to establish that the fluctuation characteristics of ocean returns are sufficiently different from those of a target. Such time-domain differences can be utilized to effect a separation of target signals from ocean clutter.

Observed fluctuations of GW radar signals

Fig. 2 shows the amplitude of a typical GW radar run collected from a range cell, at a distance of 11.4 km., containing ocean returns only. The signal energy appeared to be arriving at the receiver in wave packets; a more detailed analysis was undertaken to define their significant characteristics. A radar data set was selected with strong Bragg signals so that, to a first approximation, the time series

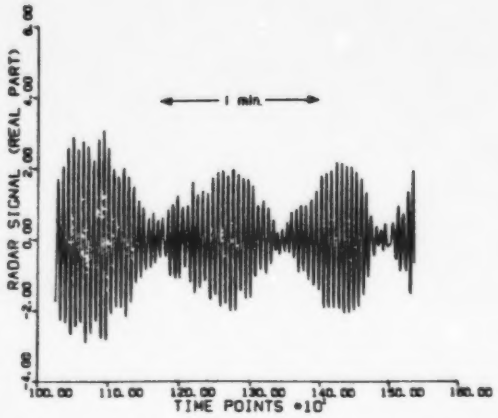

Fig. 2. Typical HFGW radar time series fluctuations.

contained the positive and negative Bragg frequencies only. We then proceeded to analyze the fluctuation behaviour of the individual Bragg components.

Priestley [4] describes a model for a non-stationary signal with additive noise; the signal having a discrete spectrum and the noise a continuous spectrum. The discrete signal components may have time-varying magnitudes and phases. A non-stationary harmonic analysis scheme called complex demodulation, to estimate the magnitudes and phases of such a process, was proposed by Tukey [5]. This technique can be applied to the analysis of the discrete Bragg components of the HF radar ocean returns. Complex demodulation at the positive and negative Bragg frequencies respectively, would then give an estimate of the time-varying characteristics of these dominant components of the ocean clutter.

Fig. 3a shows the time-varying magnitude of the negative Bragg frequency and the wave packet behaviour is clearly visible. Similar wave packets can be identified for the positive Bragg frequency in Fig. 3b. There appears to be no correlation between the locations of the two sets of wave packets. Analysis of the time-varying phases of the Bragg components reveals another significant characteristic. There appears to be a random phase change of the received signal between any two consecutive wave packets.

Modelling fluctuations of GW radar signals

As suggested by the observed time-domain behaviour of the dominant ocean returns, the Bragg scattering signals are modelled as wave packets. These wave packets exist, on the average, for a finite period of time defined as the Bragg frequency temporal coherence period. A fundamental aspect of this model is that the individual wave packets have a random phase. Thus, assuming overlapping wave packets, the time-domain radar return at the Bragg frequency could be modelled as shown in Fig. 4. The envelope of each wave packet could be modelled by a simple curve, possibly Gaussian, and would have random amplitude, length and separation (or overlap) parameters. The signals from individual wave packets are simply summed to give the component of the radar signal corresponding to the positive Bragg frequency. Another component, corresponding to the negative

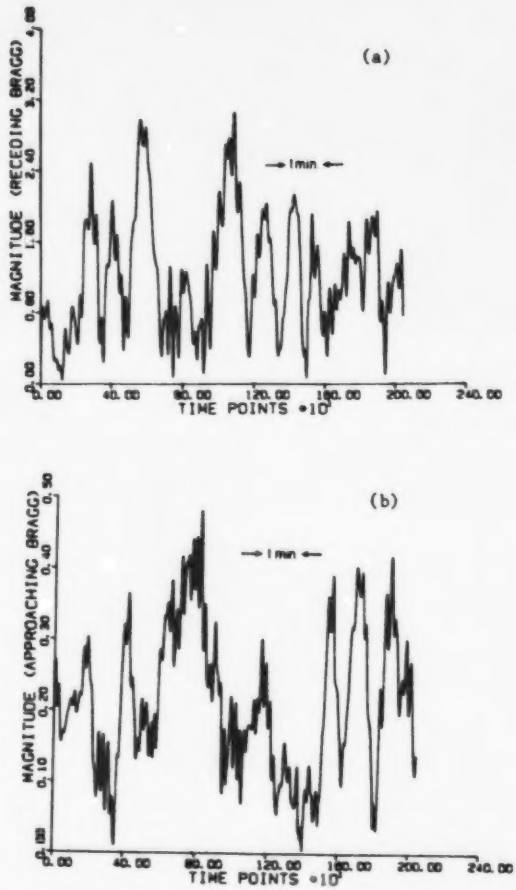

Fig. 3. Magnitude fluctuations of ocean clutter component corresponding to a) negative and b) positive Bragg frequencies.

Bragg frequency, would be further added to give us the simplest case of simulated Bragg returns from the ocean surface.

The behaviour of the signal auto-correlation is also consistent with the predictions of the wave packet model. To show this we estimate the general trend of the auto-correlation of the simulated time series of Fig. 4, and compare with the auto-correlations from real radar signals. The auto-correlation component A, in Fig. 5, corresponds to the sum of the auto-correlations of the individual wave packets in the simulated time series. All the other auto-correlation components B,C,D etc, would actually be the sums of the cross-correlations of different wave packet pairs. For example, the component C would be the sum of the cross-correlations between wave packets (k) and wave packets (k+2), for k = 1,2, ... N-2, where N is the total number of wave packets in the observation interval. The total auto-correlation thus exhibits a strong correlation at low lags followed by a periodic characteristic with a weaker correlation. This period would give an indication of the average temporal coherence length of the wave packets. These predicted characteristics have been observed in auto-correlations of real radar data. Fig. 6 shows a typical complex auto-correlation of a GW radar signal from an ocean patch at a range of 11.4 km. A periodic characteristic is clearly visible; more importantly, the correlation in the first period is

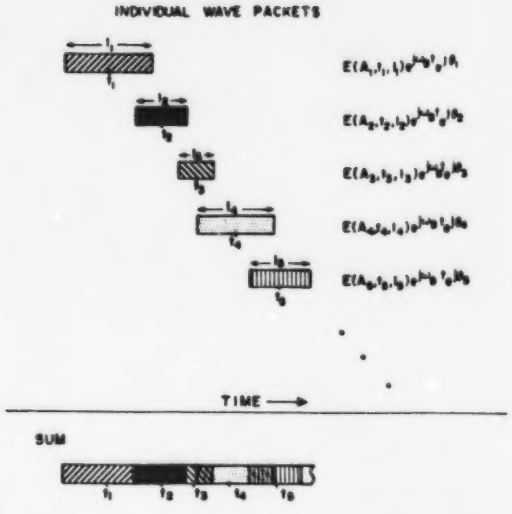

Fig. 4. Simulated time series synthesized by summing the contributions from individual wave packets corresponding to scattering returns from approaching "Bragg" waves with frequency ω_B and θ_A. E is envelope function with parameters of amplitude A_i, time t_i and length l_i.

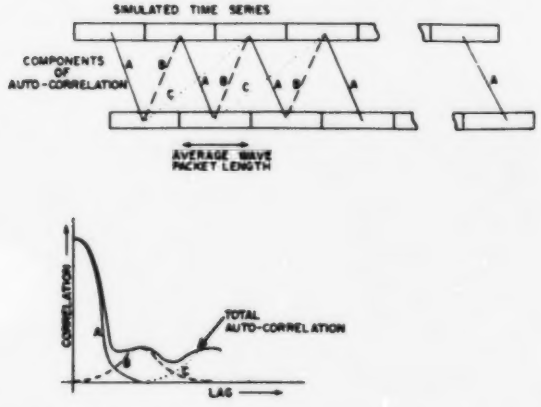

Fig. 5. Estimation of auto-correlation of simulated time series. Component A corresponds to sum of auto-correlations of wave packets. Other components B, C,... are sums of cross-correlations of wave packets.

high whereas the correlation in the second and subsequent periods has a uniform trend at a much lower level.

One of the implications of the wave packet model is that all the spectral information of the dominant Bragg returns is contained within the auto-correlation lags between 0 and τ_B sec, where τ_B is the Bragg wave temporal coherence period. On the other hand, the returns from a uniformly moving target would affect the auto-correlation equally for all lags. This is our basis for discriminating between target returns and the dominant component of ocean clutter.

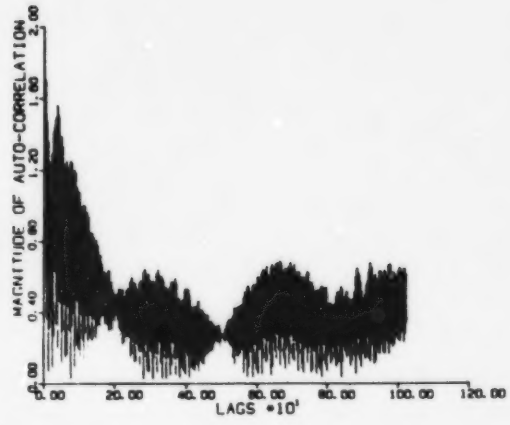

Fig. 6. Auto-correlation of HFGW radar signal containing ocean returns only (range 11.4 km).

ENHANCED TARGET DETECTION WITH GW RADAR

According to the proposed wave packet model, the auto-correlation of ocean clutter has a limited extent whereas the target auto-correlation is only limited by the observation time. In this section we present results from a non-stationary spectral analysis technique, based on the Wigner-Ville distribution, which uses this difference in the auto-correlations to enhance the GW radar target spectrum in the presence of ocean clutter.

The Wigner-Ville distribution (WD) is a relatively new analytical tool for studying non-stationary signals (see for example [6]). The WD can be used to estimate the frequency content of a signal at each point in time and, for a signal f(t), is defined as:

$$W_f(t,\omega) = \int_{-\infty}^{\infty} f(t+\tau/2)\, f^*(t-\tau/2)\, e^{-j\omega\tau}\, d\tau \quad (1)$$

It can be easily shown that the expected value of the WD over time is equivalent to the power spectrum S ( ) of the signal:

$$\int_{-\infty}^{\infty} W_f(t,\omega)\, dt = \int_{\tau=-\infty}^{\infty} \underbrace{\int_{t=-\infty}^{\infty} f(t+\tau/2)\, f^*(t-\tau/2)\, dt}_{\text{auto-correlation } R_f(\tau)}\, e^{-j\omega\tau}\, d\tau$$

$$= S_f(\omega) \quad (2)$$

Comparison of equations (1) and (2) leads to the concept of a short-time averaged WD, over a T sec. long window, as a more robust estimator of the time-varying power spectrum of the signal:

$$\overline{S}_f^T(t,\omega) = \int_{t-T/2}^{t+T/2} W_f(t',\omega)\, dt' \quad (3)$$

$$= \int_{\tau=-\infty}^{\infty} \int_{t-T/2}^{t+T/2} f(t'+\tau/2)\, f^*(t'-\tau/2)\, dt'\, e^{-j\omega\tau} d\tau$$

The transform of equation (3) has been implemented in software and the results of preliminary tests on real radar data are presented below.

A ship detection experiment was performed in June 1987 using a ground wave radar system at Cappahayden, on the SE part of the Avalon Peninsula in Newfoundland [7]. The system, operating at 25.4 MHz, used a wide beam transmit antenna and the 6 degree beam-width receive antenna consisted of twelve

quarter wave monopole elements spaced 9.45m apart.

Fig. 7 shows a non-stationary spectral analysis, using a time-averaged WD, performed on the GW radar signals from a range of 42.6 km. The ship signal as well as the Bragg ocean returns can be clearly

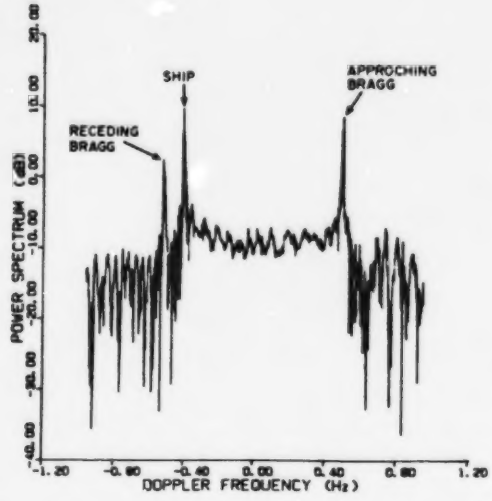

Fig. 7. Power spectrum of radar signal, containing a ship return, estimated using Wigner-based processing (range 42.6 km).

identified. This was the maximum range at which conventional processing was capable of detecting the ship, as shown in Fig. 8. The WD-based processing has significantly improved the signal-to-noise ratio.

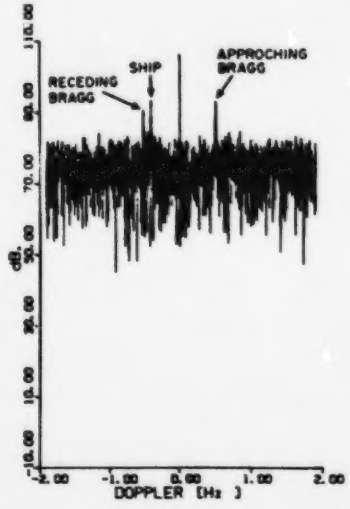

Fig. 8. Power spectrum of radar signal, containing a ship return, estimated using FFT-based processing (range 42.6 km).

SUMMARY AND CONCLUSIONS

HF radar systems, operating in the GW mode, show great potential for OTH detection of targets. The offshore resource development industry has an immediate need for such a device to provide surveillance of ice hazards. For this application, we are investigating various aspects of the radar performance to design a system optimised for target detection. Enhancing target detection demands better modelling of the target and/or interference signals. We are developing time-domain models for the dominant components of ocean clutter and demonstrate enhanced target detection using techniques based on this model.

ACKNOWLEDGEMENTS

The project is funded by the University-Industry program of the Natural Sciences and Engineering Council (NSERC) of Canada. The industrial partners for this program are Mobil Oil Canada Ltd. and Husky / Bow Valley East Coast Project.

One of the authors (RHK) would also like to acknowledge support from NSERC in the form of an operating grant.

REFERENCES

1. Crombie, D.C. (1955), "Doppler Spectrum of Sea Echo at 13.56 Mc/s," Nature, vol. 175, 681-682.

2. Barrick, D.E. (1972), "Remote sensing of sea state by radar," in Remote Sensing of the Troposphere, V.E. Derr, Ed., Washington, DC: GPO, pp. 12.1 - 12.45.

3. Srivastava, S.K. (1984), "Scattering of high frequency electromagnetic waves from an ocean surface: An alternate approach incorporating a dipole source," Ph.D. dissertation, Memorial Univ. of Newfoundland, St. John's, Nfld., Canada.

4. Priestley, M.B. (1981), "Spectral Analysis and Time Series," Academic Press Inc., New York.

5. Tukey, J.W. (1961), "Discussion emphasising the connection between analysis of variance and spectrum analysis," Technometrics, vol. 3, 191-219.

6. Boashash, B. (1987), " Non-stationary signals and the Wigner-Ville Distributions: A Review, ISSPA 87," Signal Processing, theories implementations and applications, B. Boashash Ed., Brisbane, Australia.

7. C-CORE/MUN Report (1987)," Proposed Northern Radar Systems Limited Ground Wave Radar."